PERGAMON

Renewable and Sustainable Energy Reviews
6 (2002) 481–512

RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS

www.elsevier.com/locate/rser

Renewable energy technologies for the Indian power sector: mitigation potential and operational strategies

Debyani Ghosh [a,*], P.R. Shukla [b], Amit Garg [c], P. Venkata Ramana [d]

[a] *Centre de Sciences Humaines (CSH), 2 Aurangzeb Road, New Delhi 110011, India*
[b] *Public Systems Group, Indian Institute of Management, Vastrapur, Ahmedabad 380015, India*
[c] *Project Management Cell, MoEF-UNDP-GEF NATCOM Project, Winrock International India; 7, Poorvi Marg, Vasant Vihar, New Delhi 110057, India*
[d] *Clean Energy Group, Winrock International, 1621 N Kent Street, Arlington VA 22209, USA*

Received 25 April 2002; accepted 10 May 2002

Abstract

The future economic development trajectory for India is likely to result in rapid and accelerated growth in energy demand, with attendant shortages and problems. Due to the predominance of fossil fuels in the generation mix, there are large negative environmental externalities caused by electricity generation. The power sector alone has a 40 percent contribution to the total carbon emissions. In this context, it is imperative to develop and promote alternative energy sources that can lead to sustainability of the energy–environment system. There are opportunities for renewable energy technologies under the new climate change regime as they meet the two basic conditions to be eligible for assistance under UNFCCC mechanisms: they contribute to global sustainability through GHG mitigation; and, they conform to national priorities by leading to the development of local capacities and infrastructure. This increases the importance of electricity generation from renewables. Considerable experience and capabilities exist in the country on renewable electricity technologies. But a number of techno–economic, market-related, and institutional barriers impede technology development and penetration. Although at present the contribution of renewable electricity is small, the capabilities promise the flexibility for responding to emerging economic, socio–environmental and sustainable development needs. This paper discusses the renewable and carbon market linkages

* Corresponding author. Tel: +1-408-241-8895; fax: +1-978-359-2410. Present address: 953 Helen Avenue, Apartment 9, Sunnyvale, CA-94086, USA.

E-mail address: debyanig@yahoo.com (D. Ghosh).

PII: S1364-0321(02)00015-1

and assesses mitigation potential of power sector renewable energy technologies under global environmental intervention scenarios for GHG emissions reduction. An overall energy system framework is used for assessing the future role of renewable energy in the power sector under baseline and different mitigation scenarios over a time frame of 35 years, between 2000 to 2035. The methodology uses an integrated bottom-up modelling framework. Looking into past performance trends and likely future developments, analysis results are compared with officially set targets for renewable energy. The paper also assesses the CDM investment potential for power sector renewables. It outlines specific policy interventions for overcoming the barriers and enhancing deployment of renewables for the future.

Keywords: Power sector; Renewable energy technologies; Global environmental interventions; Carbon mitigation; Operational strategies

Contents

1. Introduction

The Indian power sector is predominantly based on fossil fuels, with about three-fifths of the country's power generation capacity being dependent on vast indigenous reserves of coal. Natural gas based generation capacity that has grown very rapidly in the last decade due to lower capital requirements, shorter construction periods, and higher efficiencies has a one-twelfth share in the overall capacity. Nuclear capacity remains restricted at about 3 percent of the total. [23] Generation based on large hydropower has continued to grow very slowly due to a number of socio–environmental barriers and has a quarter share in capacity at present [1]. Renewable technology capacity (renewables in this paper refer to small hydro, wind, cogeneration and biomass-based power generation, and solar technologies and exclude large hydropower), aggregating 3000 MW as at December 2000, has a three percent share in the overall generation capacity and a one percent share in the overall generation [8]. This is a minuscule 3 percent of the present estimated potential of renewables in the country at 100,000 MW [12]. Table 1 shows the installed capacities of the technologies vis-à-vis their estimated potential.

Electricity generation from renewables is assuming increasing importance in the context of large negative environmental externalities caused by electricity generation, due to the predominance of fossil fuels in the generation mix. Managing environmental and social impacts has been drawing considerable attention in policy-making, project development, and operations. Over the past three decades there has been a gradual shift from underground to surface mining that has caused significant deforestation and land degradation [6]. There is increasing environmental concern about the contribution of coal-fired power generation to air emissions, mainly due to the poor quality of Indian coal with an average ash content of 40 percent or more. High ash

Table 1
Progress of renewable energy technologies for electricity generation

Technology	Cumulative installation as on 31st December, 2000	Estimated potential
Small hydro (MW)	1341	15,000
Wind (MW)	1267	45,000
Biomass and cogeneration[a] (MW)	308	19,500
Solar PV[b] (MW)	47 MWp	
Solar thermal (MW)	*	
Note: The potential for solar energy is estimated at 20 MW/km^2		

Source: MNES Annual Report, 2000–2001.*A 140 MW integrated solar combined cycle power plant (ISCCPP) is being implemented at Mathania in Jodhpur, Rajasthan.

[a] Estimation of the biomass and cogeneration potential is at 16000 MW and 3500 MW, respectively. The installed capacity of biomass-based combustion power is 63 MW and cogeneration based power generation capacity aggregates to 210 MW. Installed capacity of biomass gasifiers is 35 MW.

[b] Among the total installed capacity, grid-interactive solar power for peak load shaving in urban centres and providing voltage support in rural areas aggregates to 1.04 MW.

content coupled with low conversion efficiencies of 33 percent in pulverized coal plants generate large amounts of ash and particulates [3], [5]. Other emitted gases are carbon dioxide (CO_2), sulphur dioxide (SO_2), and nitrogen oxides (NO_x). Studies have shown that the power sector contributes about 40 percent of the total carbon emissions [23]. The future economic development trajectory is likely to result in rapid and accelerated growth in energy demand, with attendant shortages and problems. The growing energy consumption is likely to lead to increasing emissions of gases, compounding the pollution problems at the local level and increasing Green House Gas (GHG) emissions. For instance, a long term projection of the business-as-usual scenario over a forty year period (1995–2035) indicates that energy consumption shall treble; electricity generation shall rise by 5.4 times; coal shall continue to be the main source of fuel and carbon emissions shall go up by 3.6 times [22]. In this context, it is imperative to develop and promote alternative energy sources that can lead to sustainability of the energy system. Although at present the contribution of renewable electricity is small, the capabilities promise the flexibility for responding to emerging economic, socio–environmental and sustainable development needs.

2. Overview of India’s renewable energy programme

The Indian renewable energy program was launched primarily as a response to the perceived rural energy crisis in the 1970s [24]. It was initiated with a target-oriented supply push approach and primarily sought to develop niche applications, such as in rural areas where grid electricity was unavailable. Cash subsidies were provided for promoting renewable energy technologies (RETs). CASE (Commission on Additional Sources of Energy) was created in 1980, and then the DNES (Department of Non-conventional Energy Sources) was set up in September, 1982 [26]. In the initial stages of the programme, the technologies were not mature and there was little international experience in implementation. However, renewables were promoted as a panacea to the energy problems, and doing ‘too much too soon’ resulted in unrealistic expectations leading to failures [16]. Limitations were imposed by targets and the allocated budgets. In some cases poor technology selection led to failures, as in the case of wind energy pumps. In the early nineties, under the economic liberalization process, the programme received an impetus with a shift in emphasis from purely subsidy-driven dissemination programs to technology promotion through the commercial route. DNES was converted into a fully-fledged Ministry (Ministry of Non-conventional Energy Sources, or MNES) in July 1992, making India the only country in the world with a ministry dedicated to promoting renewable energy technologies (RETs) [12]. The technology push approach embodied fiscal and financial incentives such as subsidised interest rates, capital subsidies, long repayment schedules, tax concessions, low import tariffs, duty waivers and accelerated depreciation. By 1998, a multi-pronged strategy led to the development of the world’s largest SPV lighting program, fourth largest wind power program, and second largest biogas and improved stove programs [13].

Although considerable experience and capabilities exist on renewable electricity technologies including the development of indigenous biomass gasifier technology and manufacturing base for wind power and solar photovoltaic, a number of barriers still remain to be overcome. The push policies adopted since the nineties have been successful in creating a fairly large and diversified manufacturing base, and an infrastructure (technology-support groups and facilities, as well as the nodal agencies) to support RET design, development, testing, and deployment. But commercialisation of the technologies have been limited due to low reliability of the devices, lack of remunerative tariffs for RET-generated electricity, and a lack of consumer-desired features (in terms of the services and the financial commitments) in the design and sales-package. Distortions in the energy and electricity prices and non-internalisation of the socio–environmental externalities have impeded the progress of RETs by adversely affecting their competitiveness compared to conventional energy sources. Lack of R&D focus and low R&D budget allocation have posed a barrier towards bringing down technology costs and enhancing their competitiveness. Adequate supporting infrastructure such as training and information programmes, operation and maintenance of the technologies and monitoring for enhancing technology penetration have not been created. Overall, the programmes have failed to develop an orientation towards commercialisation of the technologies along with providing energy services to the consumer with the setting up of marketing, sales and servicing infrastructure. The existing status of specific renewable energy technologies and issues related to technology penetration are discussed here.

2.1. Small hydro power

The present installed capacity of hydro based power generation up to 25 MW capacity, classified as small hydropower, is 1341 MW [13] and estimates of MNES place the potential at 15,000 MW [28]. Since a large potential of this technology exists in remote hilly areas, development of small hydropower for decentralised power generation can lead to rural electrification and local area development. There is a well-established manufacturing base for the full range and type of small hydro equipment in the country. The government is offering a number of incentives for the development of this sector, with special emphasis on mini/micro hydel projects in remote hilly regions. Most of the small hydro power projects are canal-based grid connected, while the rest are stand-alone ones that are decentralized and are managed by local community/NGOs. High investment costs for small hydropower development has impeded its penetration. Investment costs are substantially high due to terrain inaccessibility and lack of suitable transportation linkages in locations where the potential exists. Places with high potential have low demand, that implies setting up of high cost transmission networks. Institutional issues such as inadequate state plan allocation, lack of coordination among planning and implementing agencies, delays in clearances and allotment of private sector projects, low priority of utilities to take up the projects, and lack of clear policy for private sector participation have slowed growth in small hydropower generation capacity. Success of small hydro development depends to a large extent on local capacity building programs, and

setting up institutional arrangements for demonstration, training and awareness programs that help in technology adaptation and maintenance.

2.2. Wind power

India has a wind power capacity of 1267 MW, generating about 6.5 billion units of electricity [12]. It occupies the fifth position in wind power installation after Germany, USA, Denmark and Spain [27]. The overall potential is estimated to be 45,000 MW, with about 10,000 MW of technical potential assuming 20 percent grid penetration [13]. Latest projections by the Ministry of Non-conventional Energy Sources plan an additional 10 GW of renewable capacity by 2012, out of which 6000 MW may come from wind power [12]. Private investment constitutes a substantial 95.5 percent of the total capacity and the rest are demonstration projects. Around 80 percent of the electricity generated is for captive consumption, while the rest is sold to the grid. For more than two decades after the Indian Wind Energy programme was initiated in 1984, government programs alone drove the demand for wind power. The sector was liberalized for private participation in 1992 supported by appropriate policy incentives, fiscal incentives and institutional arrangements that altered the competitive advantage of wind power and generated significant demand 'pull' by the private sector [23]. Banking and foreign exchange reforms aided this. Figure 1 shows the growth in wind power capacity. The spurt in capacity was caused partly by the dumping of wind power equipment to India from California, which was witnessing a decline in the wind energy programme. Large imports took place from

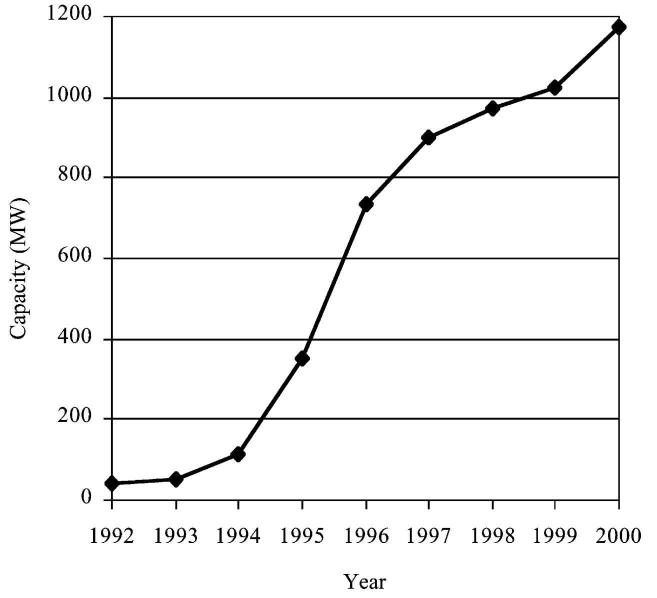

Fig. 1. Progress in wind power.

Denmark and the Netherlands too. But this equipment often had quality problems so that the generation remained low.

After a period of explosive growth, the wind power capacity growth rate declined from mid-1996 to the end of 1998, caused primarily by the unsustainability of financial incentives for promoting wind power development. Rising use of wind power—fuelled by tax rebates—increased tax revenue losses to levels that were financially unsustainable for the government budget. Low capacity utilisation (the assessment was based on 20 percent utilisation, but in most cases they were found to be lower) raised generation costs. Attractiveness of private investment in wind power projects declined with the imposition of MAT (Minimum Alternate Tax) that lowered tax-credit benefits, lowering of corporate income tax by the Union Government, withdrawal of third-party sales in some states and fluctuating and inconsistent policy regimes across states. [9] The future of wind power development lies in cost reductions, improved technical performance and financial incentives, and spread of wind power systems through global conventions and mechanisms [19].

2.3. Biomass-based power generation/cogeneration

Biomass, consisting of woodfuels, crop residues and animal dung, continues to dominate energy supply in rural and traditional sectors, having about a one-third share in the total primary energy consumption in the country. Cogeneration technology, based on multiple and sequential use of a fuel for generation of steam and power, aims at surplus power generation in process industries such as sugar mills, paper mills and rice mills, among others. The aggregate biomass combustion based power and sugar-cogeneration capacity by the end of December 2000 was 273 MW, with 210 MW of cogeneration and the rest biomass power [12]. In the area of small-scale biomass gasification, a total capacity of 35 MW has so far been installed, mainly for stand-alone applications [27]. The combined potential of biomass and sugar-cogeneration based power generation is estimated to be 19.5 GW [13]. The cogeneration potential from bagasse in the existing 430 sugar mills is about 3.5 GW [28]. Power generation systems range from small scale (5–100 kW), medium scale (1–10 MW) to large-scale (about 50 MW) applications [20]. A National Biomass Power program is being implemented, the main objectives of which are to establish techno–economic feasibility of power generation from biomass materials [19].

A shift in the perspective with respect to biomass energy strategies will be necessary to treat biomass as a competitive and modern energy supply source, reorient technology policy, integrate biomass policy with development and environment policy and support development of competitive energy markets using biomass technologies [18]. Setting up of large-scale biomass based power requires ensuring a continued and reliable supply of biomass, especially woodfuels. This in turn implies enhanced production of energy crops where critical issues related to land availability, enhancing productivity through technological interventions and other economic operations related to biomass supply will come to the fore. Growth in cogeneration capacity is constrained by large incremental investment requirements for industries, channeling of sugarcane bagasse for alternative uses, e.g. for paper production, tech-

nical barriers in upgrading of existing sugar mills and installation of power generation systems, and synchronisation and feeding of electricity to the grid [30]. Short-term measures to enhance technology penetration could include increased utilization of existing biomass, information dissemination programmes to promote usage, and better institutional coordination. Medium term measures would include development of scale economy based technologies, R&D of conversion technologies, and removal of distortions in energy tariffs. In the long run, the infrastructure related to biomass energy usage needs to be adequately developed along with institutions and policies for competitive biomass energy service markets.

2.4. Solar technologies

Solar photovoltaics (SPV) with an aggregate capacity of 47 MWp, has a two and a half percent contribution in the renewable based power generation capacity [23]. Solar thermal power generation potential in India is about 35 MW per sq. km [12]. Estimates indicate 800 MW per year potential for solar thermal based power generation in India during the period 2010 to 2015, with worldwide advancements in the parabolic trough technology [28]. A project for setting up of a 140 MW integrated solar combined cycle power project has been initiated at Jodhpur in Rajasthan. It comprises of a 35 MW solar thermal component based on parabolic trough collectors and 105 MW power generation based on naphtha/gas [27]. The SPV programme was launched in the early nineties and developed two distinct components: (i) a socially oriented dissemination program implemented by state nodal agencies with MNES subsidies; and (ii) a market-oriented scheme implemented by the Indian Renewable Energy Development Agency (IREDA) with financial assistance from international agencies [26]. At present, about 80 percent of the silicon wafers needed for the manufacture of solar cells are imported [27].

Solar technology growth has been primarily restricted by very high investment costs of the order of Rs.20 crores/MW for SPV and Rs.11 crores/MW for Solar Thermal [17].[1] Electricity generation costs from SPV on a life cycle basis is over ten times higher compared to coal-fired thermal power [23]. Commercialisation of SPV technology involves high transaction costs such as: expensive and time consuming project identification; challenging project implementation in a number of small-scale installations; high costs of credit collection and risks associated with marketing, contracting and information collection; conducting promotion campaigns and creating after sales service infrastructure; cost of co-financing, conducting feasibility studies and developing business plans. Studies on solar penetration for off-grid power systems in developing countries such as India, Indonesia and Sri Lanka reveal that access to credit in rural areas is one of the single most important factors influencing diffusion of Solar Home Systems (SHS) [11]. Some of the key policy lessons derived from World Bank experiences are ensuring the flow of rural credit through appropri-

[1] All monetary figures in this paper are in 1999–2000 prices and assume a conversion rate of Rs. 47 to a US dollar.

ately designed channels by selection of credit organisations having a strong network in rural areas, offering long-term loans to entrepreneurial start-up companies which becomes critical to rapid development of market infrastructure, phasing out of import duties on PV modules, and providing supply side grants for the rapid development of a market infrastructure for technology dissemination.

The following sections of the paper assess the carbon mitigation potential of renewable energy technologies in the power sector under different scenarios of global environmental interventions, and outline strategies for renewable energy development and penetration. Assessment of the mitigation potential involves construction of long-tem renewable energy trajectories under baseline and carbon mitigation scenarios. The baseline scenario, that assumes the most likely trajectory of future events under business-as-usual likely to affect power sector renewable energy usage, is used as a benchmark for assessing the mitigation potential under global environmental intervention futures.

3. Assessment framework

An overall energy system framework is used for assessing the future role of renewable energy in the power sector. The analysis is carried out over a time frame of 35 years, between 2000 to 2035. The methodology uses an integrated bottom-up modelling framework that has the following components: an energy systems model, individual end-use sector models and a demand projection model that separately projects demands for thirty-seven end use services. These bottom-up models have detailed representation of technological options in energy supply and enduse sectors in terms of costs, fuel inputs and emission characteristics. Energy system analysis uses MARKAL (Market Allocation), which is an energy systems optimization model [2,7,25]. For each period, the MARKAL model decides the energy and technology while minimizing the discounted capital and energy cost. The energy enduse sectors are broadly categorised as industries, transportation, agriculture, residential and commercial. Each enduse sector is analysed individually using the AIM/ENDUSE model (Asian–Pacific Integrated Model—End-use Component) that selects the technology mix within each end-use sector while minimizing the discounted costs of capital, energy and materials [14,15,10]. Soft-linkage between the energy supply and demand side takes place by providing the technology mix for each end-use sector from the AIM/ENDUSE model as an input to MARKAL together with exogenous bounds on technology penetration [22]. The demand model for the projection of enduse energy services uses the logistic regression method (representing transition from high growth to saturation) based on past sector level consumption data and expert opinion on future trajectories of these sectors. Similar representation is commonly used for technology penetration in the energy and environment context [4].

3.1. Scenarios

Assessment of the carbon mitigation potential of renewable energy technologies in the power sector examines renewable energy options for electricity generation

under a baseline scenario and scenarios that incorporate global environmental interventions. Exogenous model specifications for these scenarios include demand trajectories derived from overall macroeconomic projections; details about technology characteristics like investment costs, life of the technologies, and their performances; bounds on technology penetration; environmental characteristics of technologies; investment availability; discount rate; energy supply and energy prices.

3.1.1. Baseline scenario

The baseline scenario presumes continuation of current energy and economic dynamics and provides a reference for comparing the impacts of policies or alternate futures. It assumes what is often called “business-as-usual” dynamics. The storyline depends on an understanding of how the energy sector dynamics, and specifically the power sector dynamics, have been evolving in the past as well as an analysis of the present situation and most likely future trajectory. Overall macroeconomic projections assume a Gross Domestic Product (GDP) growth rate of 5 percent CARG (compounded annual rate of growth) over a period of the next 35 years (2000–2035). The GDP trajectory follows an S-shaped curve, with a 6 percent growth rate in initial years that saturates to 4 percent in later periods. The logistic regression method is used for end-use demand projections while maintaining overall consistency with the macroeconomic projections. The scenario assumes structural changes in the economy based on present dynamics and expert opinion on future growth trajectories of the different enduse sectors. For example, the baseline has a rising share of commercial sector with increasing service orientation, and a decline in agricultural sector share in gross value additions. Among energy forms, domestic coal supply continues to dominate but the imported natural gas supply increases with domestic gas reserves likely to be exhausted by 2015. This scenario presumes no policy interventions for GHG emissions control other than normal non-market and long-term policy interventions related to energy and technology.

3.1.2. Global environmental intervention (GEI) scenarios

The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system [21]. Rising energy demand has led to a rapidly rising trend of energy emissions from India. Although the per capita carbon emissions for India are quite low at present (about 20 times lower than US per capita emissions), total annual emissions exceed 200 million tonnes of carbon [23]. The economy has high carbon intensity due to a large share of coal in the energy mix. Following a low carbon intensity path is complicated by the fact that there are large indigenous coal reserves, but limited oil and gas reserves. While India has experience with emerging renewable technologies, the capital and foreign exchange constraints are likely to restrict a shift away from coal, unless the economic and fiscal policies to relax these constraints are instituted under a cooperative global regime. There are opportunities for RETs under the new climate change regime as they meet the two basic conditions to be eligible for assistance under UNFCCC mechanisms: they contribute to global sus-

tainability through GHG mitigation; and they conform to national priorities by leading to the development of local capacities and infrastructure. In this context, issues related to compliance of developing countries towards participation in GHG adaptation and mitigation activities and setting up of related business opportunities need to be kept in mind. At present, the only mechanism by which a developing country like India can participate in the global emissions limitations regime is through a cooperative instrument such as the Clean Development Mechanism (CDM). CDM is a voluntary mechanism for promoting GHG emissions mitigation projects in Non-Annex I countries in cooperation with Annex I countries [29]. CDM projects can reap benefits such as technology transfers, improvements in local environment and share of surplus from CDM projects [22].

This paper studies the impact on power sector renewable energy technologies in the context of overall energy system response to global carbon market signals. The analysis here considers five scenarios with different levels of carbon emission reduction targets. The scenarios aim at 5, 10, 15, 20 and 25 percent reduction over cumulative baseline emissions between 2005 to 2035 for the entire energy system. The scenario with the 5 percent reduction target is referred to as low mitigation, the 15 percent one as medium and the 25 percent one as the high mitigation scenario.

4. Analysis results

4.1. Technology trajectories

4.1.1. Projections under baseline

4.1.1.1. Overall capacity mix projections Under baseline, analysis results show an overall declining electrical energy intensity. While there is a five-fold increase in electricity demand over 2000 to 2035, the economy is projected to grow sevenfold over the same period. The electricity generation capacity almost triples over a 35-year period (395 GW in 2035), with coal continuing its dominance in the capacity mix with a declining share from the present 60 percent to 50 percent of the generation capacity in 2035. The natural gas based capacity share increases substantially from the present 7 percent to one-fifth of the total capacity in 2035, due to increasing competitiveness of natural gas based generation. Large hydro attains a 70 GW capacity in 2035, while maintaining a fifth share in the overall capacity. Nuclear has a 5 percent capacity share in 2035, up from the present 2 percent.

4.1.1.2. Projections for renewables Renewables in the power sector grow faster than the overall generation capacity. Renewable based capacity increases thirteen times over 2000 to 2035, reaching 22 GW in 2035 (Fig. 2). Under baseline, their share in overall capacity increases from the present 3 percent to 6 percent in 2035. Renewables have a 5 percent share in generation in 2035, the present figures for which are less than 1 percent. Latest projections by the Ministry of Non-conventional Energy Sources plan an additional 10 GW of renewable capacity between 2000 and 2012, constituting 10 percent of the overall power generation capacity additions [12].

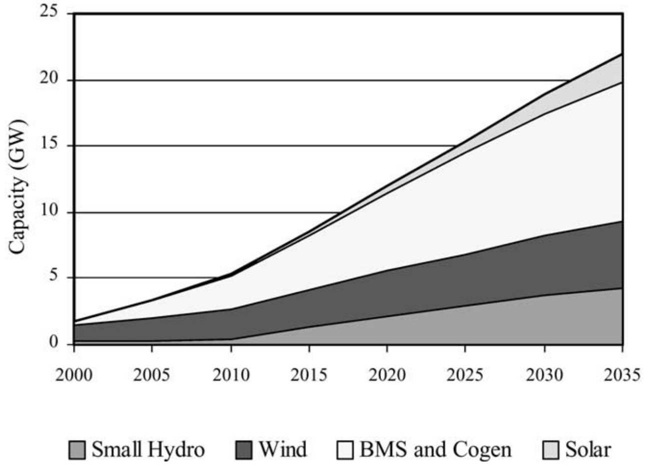

Fig. 2. Projections of renewable capacities under baseline.

Our baseline scenario results project a capacity addition of 6 GW in the same time period, that is 60 percent of the government target. Additional capacity build-up is constrained by a number of barriers, primary among them being investment availability. These are discussed later in the paper.

There is a doubling of wind capacity by 2010, that slows down in later years and attains 5 GW capacity by 2035. Wind has less than a 20 percent generation share among renewable technologies, caused by low capacity utilisation of wind turbines guided by the wind availability regime. A technology push policy along with R&D thrust and learning innovations enhances technology penetration in the short and medium run. But in the long run, wind power growth is driven by development of indigenous manufacturing capabilities and increasing competitiveness of wind technology. Biomass and cogeneration technology capacities increase substantially from their present level (50 percent share in renewable capacities from 2015 onwards), attaining 4 GW by 2015 and 10 GW by 2035. The technological attractiveness of cogeneration technology due to its high conversion efficiency and relatively low investment requirements in sugar mills, as compared to other renewables, along with favourable policy initiatives leads to a rapid capacity growth within the next decade. Small hydro capacity attains 4.3 GW by 2035, increasing its share in renewables capacity from the present 9 percent to a fifth of the total. It has a 15 percent share in the generation from renewables. The aggregate capacity of solar PV and solar thermal technologies reaches 2 GW by 2035, thereby increasing their capacity share in renewables from 2 percent now to about 10 percent by 2035.

4.1.2. Projections under the global environmental interventions (GEI) scenario

Global environmental interventions cause significant alterations in renewable energy trajectories from baseline (Table 2 and Fig. 3). Our analysis shows that cumulative carbon emissions from the entire energy system under baseline approximate

Table 2
Renewable capacities across scenarios (GW)

Scenarios	2015	2025	2035
Baseline	8	15	22
GEIlow mitigation	10	18	28
Medium mitigation	12	25	41
High mitigation	18	35	58

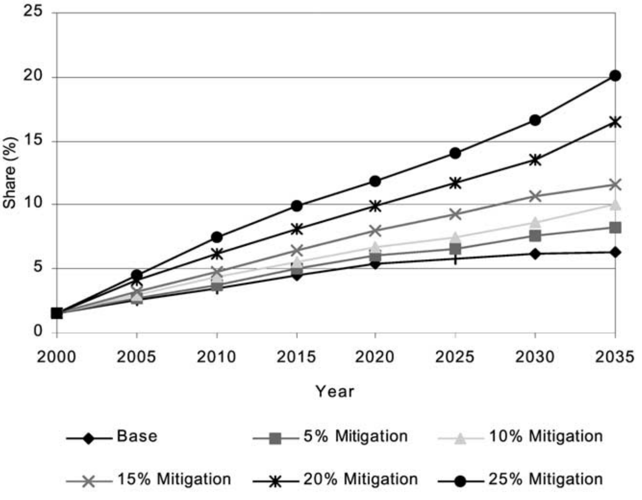

Fig. 3. Share of renewables in overall power generation capacity.

20 BT between 2000 and 2035. A weak mitigation scenario that reduces the overall energy system carbon emissions by 1 BT between 2000 and 2035 (5 percent reduction in cumulative emissions over baseline) drives the power sector renewable capacity up by 5 percent over baseline as early as 2005. Renewable capacity increases by more than 10 percent over baseline in the short-term (by 2015), by a fifth in the medium-term (by 2025) and by a third in the long-term (2035). A medium mitigation scenario that reduces overall energy system carbon emissions by 3 BT between 2000 and 2035 (15 percent reduction in cumulative emissions over baseline) demands early action in the next few years and drives up renewable capacity by one-third over baseline in 2005. In this scenario, renewables have a 45 percent capacity increase over baseline by 2015, a 60 percent increase in the medium term (by 2025) and almost a doubling of baseline capacity in the long-term (2035). A strong mitigation scenario that reduces overall energy system carbon emissions by 5 BT between 2000 and 2035 (25 percent reduction in cumulative emissions over baseline) significantly alters the technology mix for electricity generation and increases the renewables capacity by more than half in the next 5 years, doubles capacity by 2015 and

leads to a three times increase in capacity of renewables by 2035 over baseline capacities.

Figures 4 to 7 show capacity projections of renewable technologies under baseline and different mitigation scenarios. Analysis results reveal that among renewable energy technologies, global environmental interventions substantially accelerate wind power penetration. Growing indigenous expertise in wind technology and enhancement of manufacturing capabilities aid capacity growth in the short and medium-term (Fig. 5). Under weak and medium mitigation scenarios, wind power capacity reaches 3 GW and 4 GW, respectively, by 2015. But a strong mitigation scenario drives capacity to around 6 GW as early as 2015. In the long-term (2035), wind power capacity increases by about a third under a weak mitigation scenario and three times over baseline capacities in the long-term. Cogeneration offers attractive short-term cheap mitigation options. Weak and medium mitigation scenarios result in a 30 to 40 percent increase in capacity, in the short-term, over baseline. Medium-term capacity rise in cogeneration, till 2015, is about one and a half times over baseline capacity under weak and medium mitigation scenarios and the capacity almost doubles under a strong control regime. The biomass share in carbon mitigation progressively increases with time. A large part of the mitigation potential will be realised in later years, driven by the setting up of a biomass fuel supply market and advancements in biomass combustion and gasification technologies (Fig. 6). Medium and strong mitigation scenarios increase capacity to one and a half to two times over baseline by 2025. A strong mitigation regime initiates the early setting up of a commercial fuel market and enhancement of technological competitiveness that increases

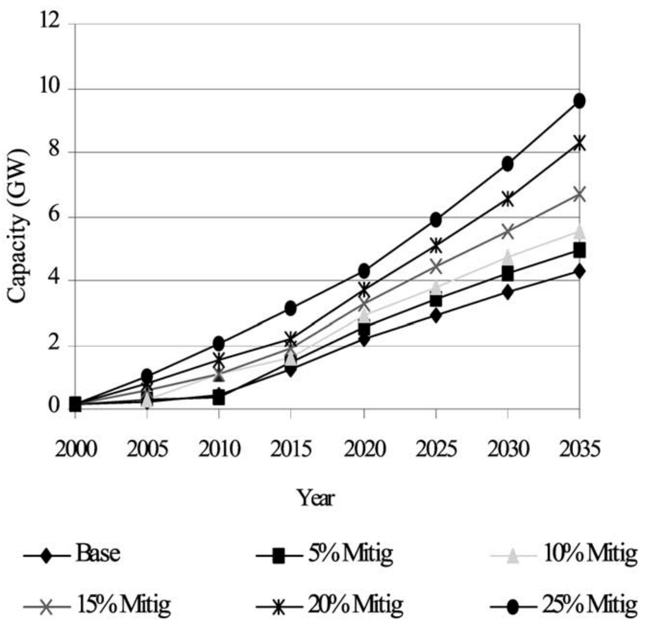

Fig. 4. Projections for small hydro capacities.

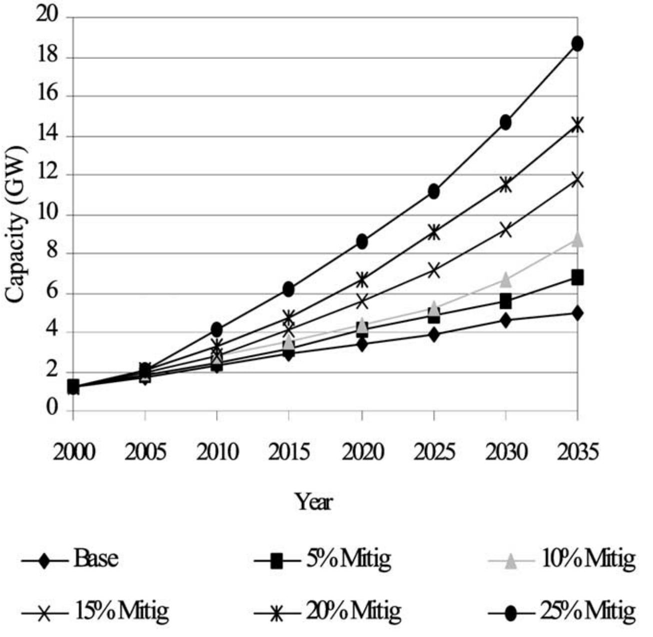

Fig. 5. Projections for wind capacities.

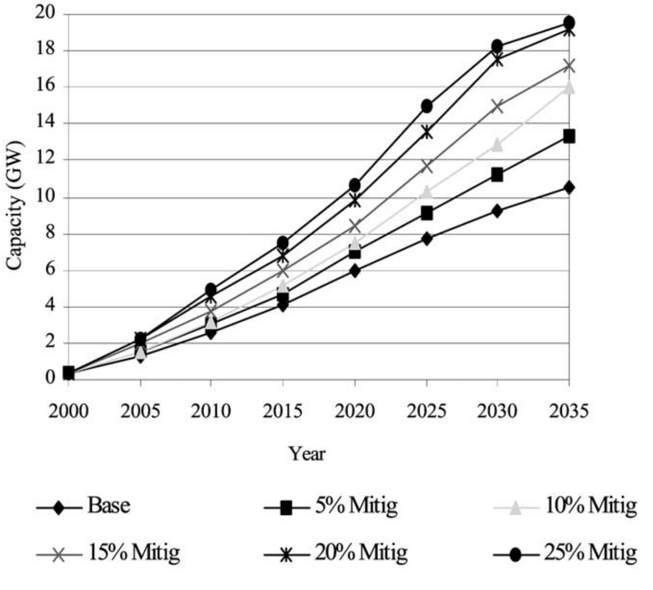

Fig. 6. Projections for biomass and cogeneration capacities.

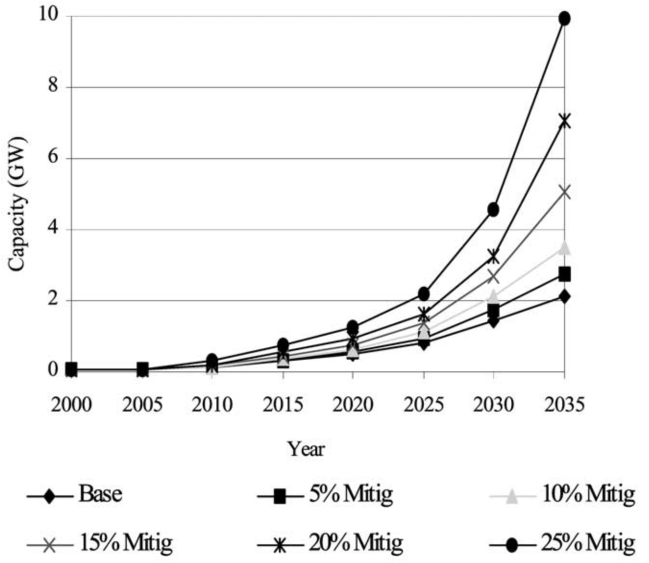

Fig. 7. Projections for solar capacities.

capacity by 80 percent over baseline as early as 2015. Actions for carbon mitigation drive the small hydro capacity up by about 1.5 times to 2.5 times over baseline in the next one and a half decades (Fig. 4). Progressively stricter mitigation requirements lead to actions on relatively costlier options such as the setting up of small hydro capacity in remote and difficult to access areas involving the setting up of costly infrastructure, within a period of two decades. There is a significant increase in solar technology capacities over baseline in the long-term, under medium and strong mitigation scenarios (Fig. 7). A global carbon market triggers enhancement of technological competitiveness by learning experiences, technology transfer mechanisms, and international co-operation in R&D in solar.

4.2. Carbon market and renewable linkages

4.2.1. Carbon mitigation potential of RETs

Analysis results estimate that renewable technologies have a 12 to 15 percent share in the overall mitigation by the power sector. The power sector share in turn is about 55 to 70 percent of the mitigation by the entire energy system, across different mitigation scenarios. The carbon supply trajectories (Fig. 8) show the cumulative emission mitigation by RETs across five mitigation scenarios. The mitigation potential of RETs show some distinct patterns (Table 3). Biomass and cogeneration technologies have more than a 60 percent share in the total mitigation by RETs, across all scenarios and time periods. Their share is higher under low and medium mitigation scenarios as compared to a strong one. These technologies have the highest share in mitigation in the short-term (by 2015), as they offer cheap mitigation opport-

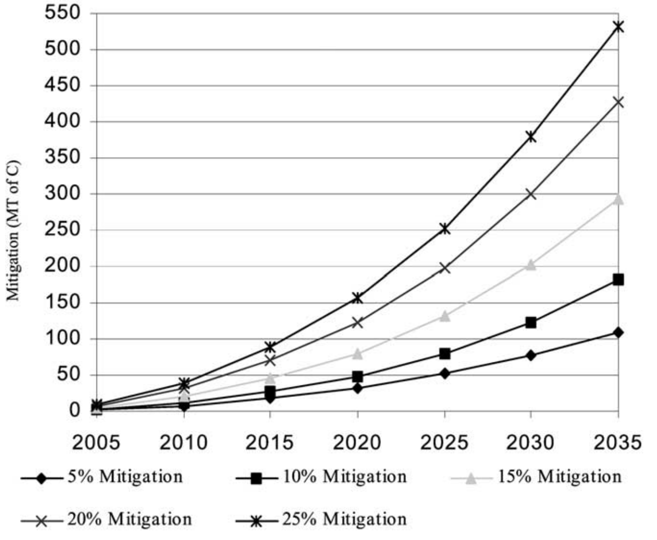

Fig. 8. Carbon supply trajectories for renewables.

unities. Wind and solar generation, being guided by availability of wind and sunshine, limits the mitigation potential of these technologies. Generation by small hydro, and hence its mitigation potential, is constrained by water availability due to sharing of water resources for irrigation purposes. Mitigation by wind progressively increases over time with stricter mitigation requirements, but their share in overall mitigation is limited to about 15 percent of the total by all renewable technologies. Most of the wind sites having high potential get tapped in early years, and exploitation of more difficult sites in later periods raises mitigation costs. Solar technologies have a higher share in mitigation in later years under stringent emission reduction requirements, but even then their shares are limited to 5 percent of the total mitigation by renewables.

4.2.2. Marginal costs of carbon mitigation

A global carbon market can initiate exploitation of the potential opportunities for carbon mitigation in India. The long-term optimal mitigation trajectory that India is going to follow will be determined by global carbon price signals. Undertaking a mitigation activity is justified only when the marginal cost of mitigation is less than the marginal benefit derived from it. Figure 9 shows the marginal cost trajectories under different mitigation scenarios for the entire energy system, derived from the modelling framework used in this paper. The marginal cost trajectories are for the entire energy system, and not for the power sector renewables alone. These reflect expectations about the global carbon price. Progressively stricter mitigation requirements increases fossil fuel costs, thereby making renewable technologies more competitive. Over time, marginal costs increase. This is because cheaper mitigation options, such as demand side improvements in the energy system, are availed of in

Table 3
Asessment of cumulative[a] carbon mitigation potential (MT of C) and shares[d]

Technologies	Scenario	Cumulative mitigation potential (MT of C)		
		2015	2025	2035
Small hydro	Low mitigation	2.6 (15)	7 (13.7)	13.8 (12.5)
	Medium mitigation	8 (17.8)	21.3 (16.3)	42.9 (14.7)
	High mitigation	20.5 (23.2)	47.6 (18.9)	93.6 (17.6)
Wind	Low mitigation	0.7 (4)	4 (7.8)	9.4 (8.5)
	Medium mitigation	3.2 (7.1)	14 (10.7)	35.7 (12.2)
	High mitigation	9.4 (10.6)	34.7 (13.8)	80.8 (15.2)
Biomass and cogeneration	Low mitigation	13.9 (80.3)	39.9 (77.9)	84.5 (76.8)
	Medium mitigation	33.2 (74.1)	93.2 (71.1)	202.4 (69.1)
	High mitigation	56.9 (64.4)	162.5 (64.5)	328.5 (61.8)
Solar	Low mitigation	0.1 (0.6)	0.3 (0.6)	2.3 (2.1)
	Medium mitigation	0.4 (0.9)	2.5 (1.9)	11.8 (4)
	High mitigation	1.5 (1.7)	7.2 (2.9)	28.6 (5.4)

[a] The cumulative estimation is from the year 2000.
[b] The numbers without brackets in the table represent the cumulative carbon mitigation potential in MT of C and the numbers in brackets represent their share in the cumulative mitigation potential of all renewable energy technologies.

earlier years and energy supply side interventions involving higher costs take place later. Demand side interventions such as improvements in efficiency of agricultural pumpsets and residential lighting systems offer no-regret mitigation choices. Such options have large additional benefits (termed as ancillary benefits) such as productivity improvements, enhanced cost effectiveness, and improvements in the quality of life, among others. On the other hand, energy supply side interventions such as adoption of advanced supercritical pulverised coal combustion technology takes a longer time due to the high inertia of the technological stock. Such changeovers are associated with large investment requirements, long life times of the technologies, and complexities in decision-making processes.

Table 4 shows the mitigation costs and contribution from the power sector renewables. A weak mitigation scenario has an average mitigation cost less than 5$/T of C till 2015. Costs increase in later years, but remain below 50$/T of C. In this

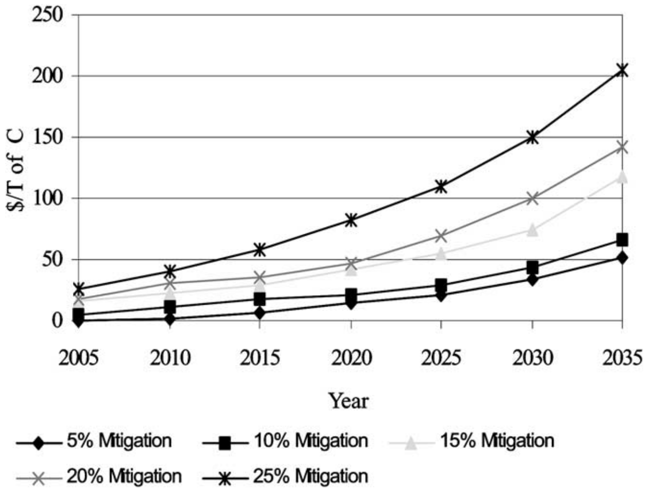

Fig. 9. Projections for marginal costs of carbon mitigation.

Table 4
Mitigation costs and contributions from RETs

	Scenarios	2015	2025	2035
Average cost[a] ($/T of C)	Low mitigation	4	18	37
	Medium mitigation	26	48	97
	High mitigation	50	97	178
Average contribution[b] ($/T of C)	Low mitigation	2.6	3.5	8.1
	Medium mitigation	3.1	6.2	20.9
	High mitigation	7.6	12.7	26.8
Cumulative contribution[c] (Billion $)	Low mitigation	0.03	0.14	0.57
	Medium mitigation	0.15	0.66	3.23
	High mitigation	0.66	2.68	9.18

[a] The average cost estimation is for a period of 5 years, i.e. the cost for 2015 is the average of the estimated cost over the period 2010–2015.

[b] The average contribution estimation is for a period of 5 years, and the time period coincides with that for average cost estimation. The average contribution estimation for each five year period is the difference between the estimated average cost for that period and global carbon price, that is reflected in the marginal cost trajectories.

[c] The starting period for cumulative contribution estimation is 2005.

scenario, the cumulative contribution from power sector renewables between 2005 and 2035 approximates half a billion dollars. A medium mitigation scenario has substantially higher costs, especially in later years, reaching close to 100$/T of C in the long term. This scenario has a five-fold increase in the cumulative contribution as compared to the low mitigation scenario. A strong mitigation scenario results in

substantial increases in mitigation costs even in the short-term due to costly energy supply side interventions, at the same time resulting in substantially higher contributions.

4.2.3. Estimation of clean development mechanism (CDM) potential

The clean development mechanism (CDM), as specified in the Kyoto Protocol to the U.N. Framework Convention on Climate Change, is the only participatory mechanism for developing country parties in project activities [29]. This paper estimates the potential CDM contribution from renewable energy technologies in the power sector (Table 5). The cumulative carbon mitigation potential during the period 2000–12 depends upon the long-term optimal emission trajectory, that is in turn dependent upon expectations on the global carbon price. We estimate the CDM contribution for all five mitigation scenarios being discussed here. A low mitigation scenario with about 10 MT of mitigation during 2000–12 provides net earnings of close to 14 million $ with the revenue reaching about 40 million $. Stricter mitigation targets lead to higher revenue as well as net contributions. Around 50 MT of carbon mitigation between 2000 and 2012 results in more than a billion $ in revenue flow, and an increase of 10 MT in mitigation targets almost doubles the revenue flow. The net CDM contribution from power sector renewables has a very wide range (15 million $ to 400 million $) over which it varies under different mitigation scenarios.

Tables 6 and 7 show the capacity additions for RETs during 2000–12 under different scenarios, with corresponding CDM contributions from RETs. Biomass and cogeneration technologies have a very high potential CDM contribution. These two technologies combined have a CDM contribution ranging between 60 to 80 percent of the total contribution from renewable technologies during the period 2000–2012, while having only 30 to 40 percent share in the additional capacity build-up over baseline. A strong mitigation trajectory (25 percent mitigation scenario) leads to

Table 5
CDM contribution from RETs (2000–2012)

	Scenarios				
	5% mitigation	10% mitigation	15% mitigation	20% mitigation	25% mitigation
Mitigation (MT of C)[a]	11	18	30	47	58
Revenue (million $)	38	231	710	1399	2573
Contribution (million $)	14	52	104	220	434
Unit contribution ($/T of C)	1.3	2.9	3.5	4.7	7.4

[a] The carbon mitigation estimation is based on assessment of the emission trajectories under baseline and mitigation scenarios.

Table 6
Cumulative new capacity installation of RETs during 2000–2012

Scenarios	Cumulative capacity addition during 2000–2012 (GW)				
	Small hydro	Wind	Biomass and cogeneration	Solar	Total
Baseline	1.5	3.3	2.9	0.15	8
5 percent mitigation	2.1	3.8	3.4	0.17	9.5
10 percent mitigation	2.8	4.6	3.6	0.19	11.2
15 percent mitigation	3.1	5.2	4.4	0.22	13
20 percent mitigation	4.1	6.6	5.1	0.32	16
25 percent mitigation	5.7	9.4	5.5	0.43	21

Table 7
CDM contribution from RETs

Scenarios	CDM contribution (million $)				
	Small hydro	Wind	Biomass and cogeneration	Solar	Total
5 percent mitigation	2.3	0.4	11.3	0.1	14
10 percent mitigation	11	4.6	36.3	0.2	52
15 percent mitigation	20.2	6	77.2	0.6	104
20 percent mitigation	46	14.5	157.8	1.7	220
25 percent mitigation	108	40	280.4	5.5	434

around 280 million $ contribution in the next twelve years from these two technologies alone. The high contribution is caused by the relatively higher share in generation from these technologies as compared to other renewables. Wind power, in spite of having a 40 percent share in the additional capacity build-up, has a less than 10 percent share in the CDM contribution. Solar technologies have a CDM contribution close to 1 percent, with a 2 percent share in the additional capacity build-up. Small hydro, with higher availability than wind and solar technologies, has a 20 to 25 percent share in CDM contribution and a 20 to 30 percent share in additional capacity. Therefore India's participation in a global carbon market in response to

global environmental interventions can boost investments in biomass and cogeneration technologies within the next decade. The analysis presumes that biomass is grown in a sustainable manner, which affirms its carbon neutrality. In this context, some of the related issues that need to be addressed are: structuring of policy incentives for private participation and investments in cogeneration for which an attractive potential exists in many industries, advancements in biomass gasification and combustion technology especially in the area of integrated gasification technology, lowering of technology costs through learning experiences, setting up of biomass supply infrastructure and development of market mechanisms for trading in this commodity along with collection, storage and transportation mechanisms, practising of sustainable agricultural practices, arrangements for grid connectivity, and rural area development programmes with local capacity building measures.

4.3. Projections for investment requirements in RETs

4.3.1. Baseline projections

Baseline investments in power sector renewables approximate 3 billion $ within the next decade and passes 6 billion $ by 2015 (Fig. 10). Investment grows faster in earlier years at an average annual rate of 5 percent, but slows down in later years to less than one percent. Among renewable technologies, wind has close to a one-third investment share within the next decade. Its investments reach a billion $ by 2010 which doubles in the following decade and reaches close to 3 billion $ by 2035, with a one-fifth share in the total renewable sector investments. Biomass and cogeneration technologies maintain a 40 to 50 percent share in investments, their deployment increasing with growing commercialisation and competitiveness of these technologies. Within the next decade, investments in these reach more than one and a

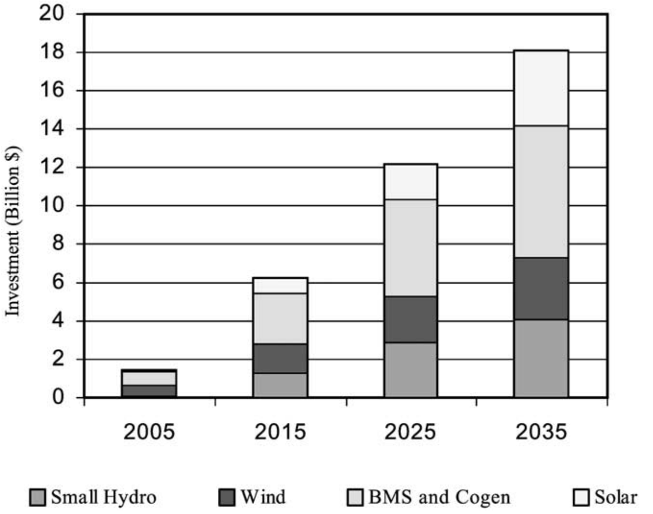

Fig. 10. Baseline investments (cumulative figures starting from 2000) in renewable energy technologies.

half billion $. The medium-term (2025) and long-term (2035) cumulative investment requirements in these technologies are close to 5 billion and 7 billion $, respectively. Cumulative investments in solar technologies are more than a billion $ in the next two decades, with a 13 percent share in the total renewable energy investments. Higher penetration of solar technologies in later time periods due to declining costs via learning experiences, technology R&D and transfer and removal of trade barriers for freer import of components result in investments reaching 4 billion $ by 2035, i.e. a one-fifth share in the total investments. Investments in small hydro reach more than a million dollars by 2015. It maintains a one-fifth share in the total renewable energy investments in the power sector. By 2025, investment requirements are 3 billion $ and are a billion more in the following decade by 2035.

4.3.2. GEI scenario projections

Carbon mitigation efforts initiate technological interventions on both the demand side and supply side of the energy system. Demand side interventions, such as enhancement of irrigation pumpset efficiencies in the agricultural sector, take place earlier as compared to supply side ones. This is because the former offers cheaper mitigation opportunities. Tightening of carbon emission constraints leads to alterations in the energy mix on the supply side, thereby increasing investments in renewable energy. Our analysis results show that adding around 8 GW of RET capacity between 2000 and 2015 reduces carbon emissions by 17 MT and has an investment requirement of 7 billion US$. Cumulative investments under stricter mitigation requirements could be of the order of 10 to 15 billion $ by 2015, from reducing carbon emissions by 45 and 90 MT, respectively, by power sector renewables.

It is interesting to compare the relative share of RETs in carbon mitigation vis-à-vis their share in investments (Figs 11 and Fig. 12). Biomass and cogeneration technologies have the highest shares in mitigation with the lowest shares in investments. They have a 60 to 80 percent share in total mitigation, while their investment

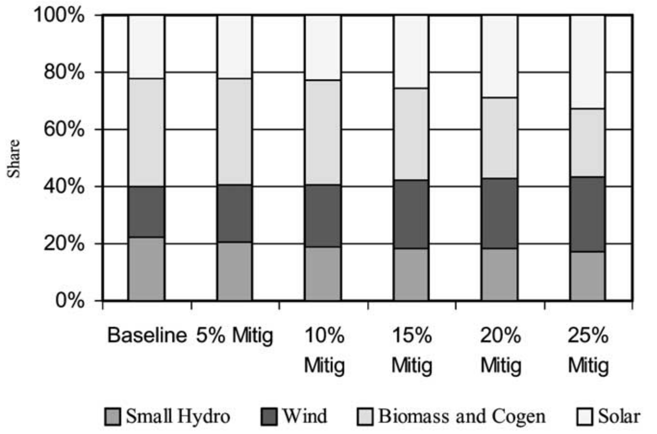

Fig. 11. Shares of RETs in cumulative investments (2000–2035).

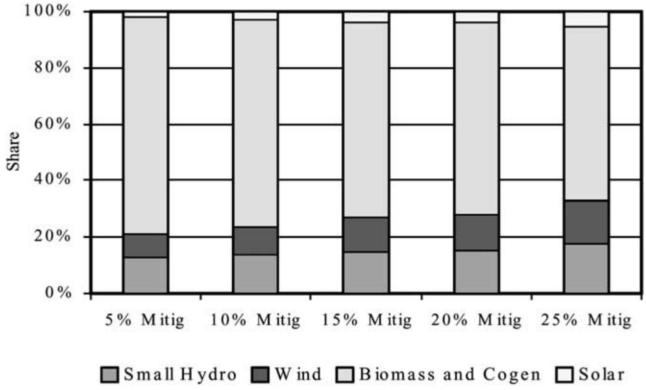

Fig. 12. Shares of RETs in cumulative mitigation (2000–2035).

share ranges between a quarter to 40 percent across different mitigation scenarios. Contrast this with solar technologies that have only a 3 to 6 percent share in mitigation, while having a relatively much higher share in investments ranging between one-fifth to a third of the total. Wind power with high investment costs and low capacity utilisation has a 10 to 15 percent share in mitigation, while having a 20 to 25 percent investment share.

Recycling of the net contribution from emissions reductions in different sectors can help in lowering mitigation costs and ensure sustainability of the regime. Some external financing mechanisms may be necessary in initial periods for undertaking mitigation activities and lowering the overall cost burden. In the power sector, recycling of carbon revenue can aid in bringing down electricity costs so that overall economic competitiveness is not affected. Analysis results show that recycling of the net contribution from 100 MT of carbon mitigation over the next 35 years, for investing in RETs, can save close to a billion $ in investments over the same time. The savings are quite substantial if strong mitigation action takes place in earlier years. If under a strong mitigation scenario, India were to mitigate about 90 MT of carbon by RETs alone in the power sector by 2015, revenue recycling could save 3 billion dollars in investment. The medium-term (2000 to 2025) savings in investment can range between half a billion to 6 billion dollars for 50 to 250 MT of carbon mitigation, respectively. Long-term reductions in investments are quite substantial. There is an investment saving of about 7 billion dollars by recycling of the contribution from close to 300 MT of carbon mitigation over 2000–2035, while for a billion tonnes of carbon mitigation over the same time frame investment saving approximates 17 billion dollars.

4.3.3. Investment potential in RETs under the clean development mechanism (CDM)

Mechanisms such as the clean development mechanism (CDM) offer investment opportunities in RETs (Fig. 13). CDM investment potential for the period 2000–2012 ranges between 1 to 7 billion $ for the five different mitigation scenarios used

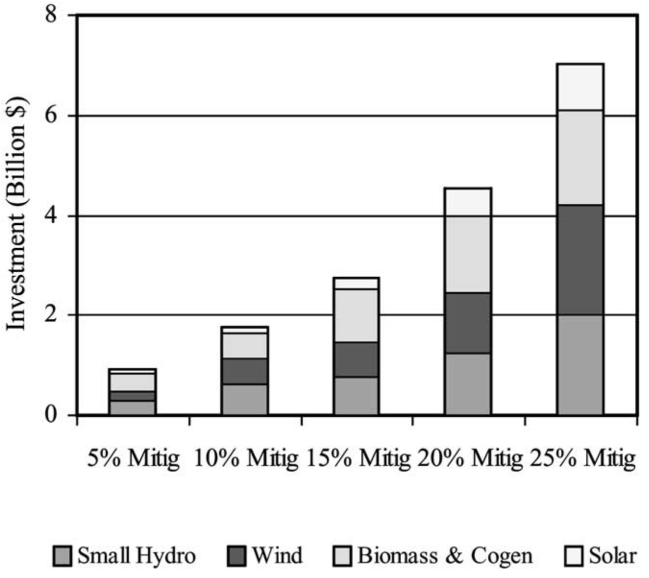

Fig. 13. CDM investment potential of RETs.

in the analysis. Following the additionality criteria under the Kyoto Protocol, 6.5 MT of carbon mitigation over baseline emissions between 2000–2012 entail a CDM investment potential of 1 billion $. A mitigation of 60 MT of carbon over the same time frame has an investment potential of 7 billion $. Biomass and cogeneration technologies have the highest share in CDM investment (30 to 40 percent share) under a low to medium mitigation scenario (5 to 15 percent mitigation scenarios) as they offer a large and relatively cheap potential that can be easily exploited compared to other RETs. The investment in these technologies can range between less than half a billion dollars to more than two billion dollars across mitigation scenarios. Stricter mitigation requirements (20 to 25 percent cumulative mitigation over baseline emissions) necessitate high investments in technologies such as wind and solar. Close to 50 MT of mitigation by RETs over 2000–2012, has an investment potential of more than a billion for wind alone. Around 60 MT of mitigation target over the same period doubles the investment potential in wind to more than 2 billion dollars. The investment potential in solar technologies under this scenario reaches about a billion dollars, that has a 13 percent share in the total RET investment potential. Small hydro maintains close to a one-third share in investments across all mitigation scenarios.

4.4. Barriers in renewable energy development and penetration

Despite the progress in renewable energy, a number of barriers restrict its development and penetration. Some RETs have relatively higher investment requirements as compared to other technologies. Intermittent electricity generation characteristics

from some renewable energy technologies lead to their low reliability in meeting power demand, necessitating back-up power supply options that increases costs. There is a lack of full cost pricing in determining the cost of competing energy supplies, and environmental externalities are not internalised. Electricity market transition conditions with high discount rates and competition on short-term electricity prices within a regulatory framework disadvantage projects, such as renewable electricity systems, with high capital costs but low running costs. In addition to cost-related barriers, non-cost barriers also inhibit the greater use of renewable energy. This is particularly the case with the imperfect flow of information and the lack of integrated planning procedures and guidelines. Table 8 lists some barriers that are broadly classified as economic and technological barriers, market-related barriers and institutional barriers.

4.5. Conclusions and operational strategies

The renewable energy programme, over its three decades of existence, has evolved with the setting up of a manufacturing base and an infrastructure to support RET design, development, testing and deployment. But the commercial demand for these technologies still remains low. Some key issues related to an operational strategy formulation for renewable energy are: integration with energy market liberalization and withdrawal of direct government interventions, enhancement of renewable energy deployment from an ‘energy services’ delivery perspective, and incorporation of renewable energy strategy into development programmes to promote decentralised applications. Renewable energy strategy should form a part of the energy sector regulatory framework. The public–private role in renewable energy development needs to be redefined. Government policies should encourage more private participation and industry collaboration in R&D for rapid commercialization of RETs and market infrastructure development. Advanced indigenous manufacturing capabilities need to be set up. International co-operation in R&D and technology transfer mechanisms through emerging instruments such as CDM need to be established. However, at present many renewables are in a classic chicken and egg situation: financiers and manufacturers are reluctant to invest the capital needed to reduce costs when demand is low and uncertain, but demand stays low because potential economies of scale cannot be realised at low levels of production. Renewables need to gain the confidence of developers, customers, planners and financiers. This can be done by renewables establishing a strong track record, performing to expectations, and improving their competitive position relative to conventional fuels. Development of hybrid technologies for a decentralized energy system with a combination of two or more technologies for greater reliability will increase renewable penetration. Faster diffusion of RETs would necessitate improved reliability of technologies and introduction of consumer-desired features (in terms of services and financial commitments) in the design and sales package. There is a need to encourage learning investments in technologies that lead to cost reductions and performance improvements. Development of an energy market incorporating the full cost pricing of energy forms and life cycle cost analysis of technologies, adopting net-metering schemes by incorporating

Table 8
Barriers in renewable energy development and penetration

Economic and technological	Market related	Institutional
Small hydro power		
Remote and dispersed availability of potential leading to demand/supply mismatchHigh Investment requirements Intermittent supply of water due to water sharing for irrigation purposesPower off-take problems due to Grid instabilities	Setting up of rural and decentralised applications involve high risk perception Non-internalisation of socio-environmental externalities in energy pricingIrrational electricity tariff structure	Inadequate orientation towards providing decentralised and rural energy servicesLow level of capacity building and mobilisation of community participationNon-uniform and unstable policies across states, inadequate allocation from state plans and low priority for utilities to take up projectsNon-inclusion in the regulatory framework
Wind power		
Tapping of wind potential difficult due to dispersion of wind resources. Low peak coincidence factor leads to problems in matching wind availability with load duration curveHigh Investment requirementsPower off-take problems due to Grid instabilitiesHigh reactive power requirements for start-up	Higher charges may be imposed under wheeling contracts on intermittent generators Fluctuating generation costs create problems in cost recovery under fixed power purchase termsSubsidy on fossil fuels and non-internalisation of socio–environmental externalitiesIrrational electricity tariff structure	Non-availability of infrastructure such as land and access to R&D networks Long-term unsustainability of present programmes based on fiscal and financial incentivesNon-uniform and unstable policies across states
Biomass and cogeneration power		
Inconsistencies in nature of biomass fuel lead to difficulties in conversionUncertainties in technological performanceTechnical barriers in upgradation of existing sugar mills for cogeneration, synchronisation and feeding electricity to GridAlternative uses for cogeneration fuel like paper productionLarge fund requirements in setting up of commercial biomass fuel (fuel wood) market for afforestation programmes, harvesting and transportation of the fuel.	Unreliable fuel supplyHigh transaction costs in setting up of biomass fuel market Difficulties in marketing and pricing of forest products pose challenges for fuel wood market creation.Non-remunerative tariff for power export from sugar mills	Land requirement for large-scale biomass cultivation may compete with foodgrain productionNon-uniform and unstable policies across states Non-inclusion in regulatory frameworkLack of orientation towards providing decentralised, rural energy services Low replicability of demonstration projects

(*continued on next page*)

Table 8 (*continued*)

Economic and technological	Market related	Institutional
Solar power		
Very high investment requirementsLow level of technological maturity Non-standardisation of technologies leading to low level of reliability Need for storage/backup technologies for supply during night-time raises costsLow peak coincidence factor Inadequate maintenance and servicing skills	High-risk perception of private investor Large pre-investment risks associated with the costs of marketing, contracting and information collectionTrade barriers imposed by high import duties for PV modulesSubsidy on fossil fuels, non-internalisation of socio–environmental externalities and irrational electricity tariff structure hinder development	High transaction costs in technology commercialisationDifficulties in technology dissemination due to inadequate marketing infrastructure and sales and services networksNot integrated in power sector reformsDifficulties in availability of finance and providing micro-credit access, especially for rural areasLow replicability of demonstration projects

avoidance costs for R&D in the electricity supply price from renewables, along with internalisation of socio–environmental externalities in the pricing of energy services will enhance competitiveness of renewables.

Future target setting and establishment of a renewable energy portfolio needs to be integrated with overall energy sector and power sector targets. Within renewables, the overall target needs to be desegregated into targets for individual RETs and renewables incorporated in the regulatory proceedings/mechanisms at the centre and states. Specific interventions need to be clearly outlined for achieving penetrations beyond baseline projections, as shown by our analysis. At present, MNES has projected 10,000 MW renewable energy capacity by 2012 for which our analysis results indicate investment requirements of approximately 8 billion $. Looking into the past performance and likely future developments under baseline, it is unlikely that such investment requirements would be mobilised unless some specific interventions take place. Our analysis projects baseline capacity to 8,000 MW by 2015 and 15,000 MW by 2020. Results also indicate that the 10,000 MW capacity target set by the government for renewable energy by 2012 matches very closely with our projections for the medium mitigation scenario. This implies that an average price of 25$/T of C offers opportunities for mitigating around 15 MT of carbon between 2005 and 2015 from renewable energy options in the power sector and lead to renewable capacity reaching close to 10,000 MW by 2012. Our analysis shows that India's participation in the clean development mechanism (CDM) or any alternative mechanisms for developing country participation under global climate change interventions, offers around 3 billion $ investment potential leading to 15 MT of mitigation. Under this scenario, renewable energy CDM projects in the power sector form a substantial 40 percent of the total investment requirements, with a net earning potential of close to 150 million $. Some technology specific measures that could form a part of renewable energy operational strategies are discussed here.

Small Hydro: Small hydro power development could be integrated with regional development plans, especially for stand-alone systems. Decentralised power generation from stand-alone small hydro sources occurring in remote hilly areas could be taken up as part of rural electrification and poverty alleviation programmes along with an upgrading program for water mills. Measures such as speeding up clearance of private power projects, de-licensing power generation from small hydro and providing investment support would encourage private participation. Adopting a bottom-up approach for technology dissemination would entail the setting up of demonstration, training and awareness programs for community empowerment and local capacity building. A critical issue is providing micro-credit and funding access from decentralised banks.

Wind: Measures need to be undertaken for better operation and maintenance of wind power systems and better technological performance leading to improved capacity utilization. The wind power supply option needs to be included in a utility unit's commitment approach. Ensuring grid stability for reliable power off-take will lead to better capacity utilisation. Encouraging private participation would require establishing a uniform and stable policy regime across states regarding third-party sales, fixing of tariffs, wheeling and banking of power. Interventions for environmen-

tal sustainability enhance wind power penetration. Baseline projections need to be redefined in the light of investment requirements and a preparedness plan developed for accelerated penetration under carbon mitigation scenarios.

Biomass and Cogeneration: Biomass energy development needs to be integrated with environment and development policies such as wasteland development programs, poverty alleviation, and rural employment generation programs. For centralised power generation applications, it is necessary to set up a commercial fuelwood market for ensuring a continuous and reliable fuel supply. Setting up of biomass energy projects would entail empowering local communities and undertaking capacity building programs. Farmers' cooperatives could be set up in catchment areas for management of plantations. Other issues include increased R&D in advanced biomass conversion technologies such as integrated cycle conversion technologies, and development of advanced manufacturing capabilities for transition from demonstration and pilot-plant stages to commercial stage. For cogeneration projects, power supply needs to be ensured from sugar mills to utilities by using supplementary fuels at the time of non-operation of sugar mills.

Solar: Solar power programs need to be integrated with regional development and rural electrification programs. This would involve mobilising community participation in decentralised system development by local capacity building, training and awareness building programs, and assistance in income generation schemes as part of their economic and social welfare. Technology transfer would be facilitated by removal of trade barriers such as high import duty on PV modules. A critical issue is development of sustainable business plans for ensuring replicability of demonstration projects. The setting up of market infrastructure would involve strong sales and service networks for providing the energy service. Sustainable financial arrangements are critical for the success of SPV programs with a network for micro-credit access. Local financiers should be encouraged to assume part of the credit risk to ensure post project sustainability and replication. Small private dealers could be encouraged to work with local micro-finance organizations or partner with large credit firms.

Acknowledgements

The authors are grateful for the support provided for this study by Indian government officials, especially from the Ministry of Non-conventional Energy Sources and Ministry of Power, Government of India.

References

[1] ASCI (Administrative Staff College of India). India: Environmental Issues in the Power Sector. Andhra Pradesh Case study. Volume III: Coal model. April. Hyderabad, India, 1998.
[2] Berger C, Haurie A, Loulou R. Modelling long range energy technology choices: the MARKAL approach. Report, GERAD, Montreal, Canada, 1987.
[3] Biswas D, editor. Parivesh Newsletter: June. Central Pollution Control Board, Ministry of Environment and Forests, Government of India, New Delhi, 2000.

[4] Edmonds J, Reilly J. A long-term energy-economic model of carbon dioxide release from fossil fuel use. Energy Economics April, 1983;5(4):74–88.
[5] ERM (Environmental Resources Management). Renewable Energy in India: A Special Study. July, New Delhi, India, 1997.
[6] ESMAP (Energy Sector Management Associate Programme). India Environmental Issues in the Power Sector. Report no. 205/98. The World Bank, June, Washington, DC, USA.
[7] Fishbone LG, Abilock HM. ARKAL, a linear programming model for energy system analysis: technical description of the BNL version. International Journal of Energy Research 1981;5:353–75.
[8] Ghosh D, Shukla PR, Garg A, Ramana PV. Renewable energy strategies for Indian power sector. Centre de Sciences Humaines (CSH) Occasional Paper no. 3/2001, A publication of the French Research Institutes in India, New Delhi, India, 2001.
[9] Jagdeesh A. Wind energy development in Tamil Nadu and Andhra Pradesh, India Instituitional dynamics and barriers. Energy Policy 2000;28:157–68.
[10] Kainuma M, Matsuoka Y, Morita T. The AIM model and simulations. AIM Interim Paper, National Institute for Environmental Studies, Tsukuba, Japan, 1997.
[11] Miller D, Hope C. Learning to lend for off-grid solar power: policy lessons from World Bank loans to India, Indonesia and Sri Lanka. Energy Policy 2000;28:87–105.
[12] MNES (Ministry of Non-conventional Energy Sources). Annual Report 2000–2001. Ministry of Non-conventional Energy Sources, New Delhi, 2001.
[13] MNES (Ministry of Non-conventional Energy Sources). Annual Report 1999–2000. Ministry of Non-conventional Energy Sources, New Delhi, 2000.
[14] Morita T, Kainuma M, Harasawa H, Kai K. A guide to the AIM/ENDUSE model—technology selection program with linear programming. AIM Interim Paper, Japan, 1996.
[15] Morita T, Kainuma M, Harasawa H, Kai K, Kun LD, Matsuoka Y. Asian–Pacific integrated model for evaluating policy options to reduce greenhouse gas emissions and global warming impacts. AIM Interim Paper, National Institute for Environmental Studies, Tsukuba, Japan, 1994.
[16] Ramana PV, Shukla PR. Climate change policies and long-term rural energy trends in India. In: Shukla PR, editor. Climate Change Mitigation: Shaping the Indian Strategy. New Delhi, India: Allied Publishers; 1998.
[17] Ramana PV. As if Institutions Matter: An Assessment of Renewable Energy Technologies in Rural India. The Netherlands: University of Twente, 1998.
[18] Ramana PV, Joshi V. Use of biomass fuels in India—trends and issues. In: Ramana PV, editor. Rural and renewable energy: perspective from developing countries. New Delhi: Tata Energy Research Institute; 1997.
[19] Ravindranath NH, Usha Rao K, Natarajan B, Monga P. Renewable Energy and Environment: A Policy Analysis for India. New Delhi, India: Tata McGraw-Hill Publishing Company Limited, 2000.
[20] Ravindranath NH, Hall DO. Biomass Energy and Environment—A Developing Country Perspective from India. Oxford: Oxford University Press, 1995.
[21] SAR. Second Assessment report of IPCC. Climate Change 1995: The Science of Climate Change. Cambridge, 1996.
[22] Shukla PR, Audinet P, Grare F, editors. India's Energy: Essays on Sustainable Development. New Delhi: Manohar Publications; 2000.
[23] Shukla PR, Ghosh D, Chandler W, Logan J. Developing Countries and Global Climate Change: Electric Power Options in India. Prepared for the Pew Centre on Global Climate Change, Arlington, US, 1999.
[24] Shukla PR. Penetration of renewable energy technologies in India: assessment of future trajectories and macro policies. In: Ramana PV, editor. Renewable and Rural Energy Policy Perspective in Developing Countries. New Delhi: Tata Energy Research Institute; 1997.
[25] Shukla PR. The modelling of policy options for greenhouse gas mitigation in India. Ambio 1996;25(4):240–8.
[26] Sinha CS. Renewable energy programs in India: some recent developments. Natural Resources Forum 1993;18(4):213–24.
[27] Tata Energy Research Institute. TERI Energy Data Directory and Yearbook. New Delhi, India: Tata Energy Research Institute, 2000/2001.

[28] Tata Energy Research Institute. TERI Energy Data Directory and Yearbook. New Delhi, India: Tata Energy Research Institute, 1999/2000.
[29] UNFCCC, Kyoto Protocol to the United Nations Framework Convention on Climate Change, United Nations, New York, 1997.
[30] Workshop Proceedings. Workshop on Policies to Accelerate Renewable Energy Market Deployment, 18–20 February, 2001: Ashoka Hotel, New Delhi, India.

Debyani Ghosh is a post-doctoral researcher in Economics at the Centre de Sciences Humaines, New Delhi, India. She is a Fellow of the Indian Institute of Management, Ahmedabad, India. Her areas of expertise are in policy analysis related to energy and environment systems, management and implementation including strategy formulation at the enterprise level, and Green House Gas (GHG) mitigation strategy analysis.

P.R. Shukla is a Professor in the Public Systems Group at the Indian Institute of Management, Ahmedabad. He holds a Ph.D. degree from Stanford University. He has worked on numerous research and consulting assignments for Indian and international organizations. Professor Shukla is a lead author of several IPCC reports and has co-authored eight books and numerous publications in international journals.

Amit Garg is a Fellow of the Indian Institute of Management, Ahmedabad, India. He has expertise in emissions inventory estimation and analysis, and energy–environment policy analysis. He has intensive experience and familiarization of working with various economy–economy–environment models like MARKAL, Stochastic-MARKAL, MARKAL-Answer, AIM Enduse, AIM Local and ERB. He has published several papers in international journals.

Venkata Ramana is currently Managing Director, Clean Energy Group, Winrock International, an NGO based in Arlington, USA and working in nearly 65 countries. He earned degrees in engineering and management and a Ph.D. in renewable energy. He has extensive international experience in design and management of clean energy programs, capacity building, institutional networking, policy analysis, and climate change issues. Ramana has been, among other things, a resource person at over 50 training courses in the energy sector around the world. Prior to Winrock, he was Assistant Resident Representative for Energy and Environment and National Coordinator for the Global Environment Facility (GEF) at UNDP in India. Before that he had extensive research experience in rural and renewable energy at the Tata Energy Research Institute (TERI), New Delhi. He has over 70 publications including books, journal articles and seminar presentations to his credit. His current interests include climate change issues and commercialization of renewable energy technologies in developing countries.